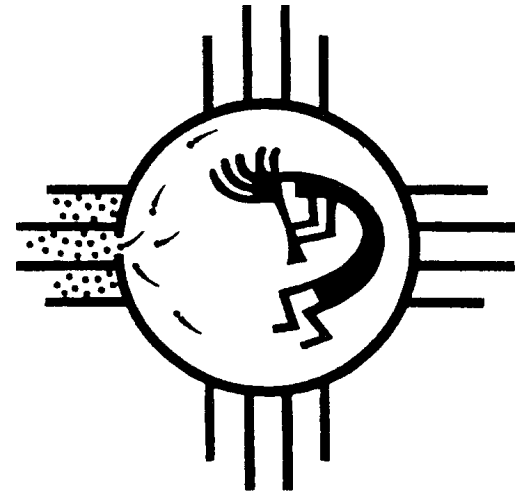


SHORT COURSE PROGRAM



*American Vacuum Society/
New Mexico Chapter*

May 13 –17, 2002

Wyndham Hotel
Albuquerque, New Mexico

Short Course Program

AMERICAN VACUUM SOCIETY/
NEW MEXICO CHAPTER

Wyndham Hotel
2910 Yale Blvd. SE
Albuquerque, New Mexico

May 13-17, 2002

- A** - Basic Vacuum Technology (5 days, Mon. - Fri., May 13-17)
- B** - Operation and Maintenance of Vacuum Pumping Systems
(2 days, Mon. & Tues., May 13 & 14)
- C** - Vacuum System Design (1day, Mon. May 13)
- D** - An Introduction to Ellipsometry (1 day, Tues. May 14)
- E** - Vacuum Leak Detection (1 day, Wed. May 15)
- F** - Cryopump Technology (1 day, Wed. May 15)
- G** - Plasma Etching and Reactive Ion Etching
 - G1 – Fundamentals (1 day, Thurs. May 16)
 - G2 - Fundamentals and Applications
(2 days, Thurs. & Fri., May 16 & 17)
- H** - Microfabrication Technology for Micro-electromechanical
Systems (1 day, Thurs. May 16)
- I** - Partial Pressure Analyzers: Analysis & Applications
(1 day, Fri. May 17)
- J** - Focused Ion Beams: Principles & Applications
(1 day, Fri. May 17)

General Information

Registration Information: Registration will be on a first received basis upon receipt of the registration form and payment of course fees. Class sizes will be limited and early registration is recommended. All registrations will receive an acknowledgement. After **May 1, 2002**, please fax registration forms to (505) 286-1308

Cancellation Policy: All courses are subject to cancellation if a sufficient number of registrations have not been received by **May 1, 2002**. Please register early to avoid cancellation of courses.

Course Location and Meeting Times: All courses meet from 8:30 AM until 4:30 PM at the Wyndham Hotel, 2910 Yale Blvd. SE, Albuquerque, NM. Take I-25 to Gibson, east on Gibson to Yale, south on Yale.

Hotel Reservations: Sleeping rooms have been reserved for course attendees at the Wyndham Hotel, 2910 Yale Blvd. SE, Albuquerque, NM, telephone (505) 843-7000. The cut off date for group rate reservations is May 1, 2002. Please identify yourself as an AVS/NMC attendee when making reservations in order to get the group rate.

Lunch/Breaks: Refreshments and a full lunch will be provided at the Wyndham Hotel for each day of the course. There will be short breaks in the morning and afternoon. Lunch will be held from 12:00 noon to 1:00 PM each day. Refreshments and lunch are included in the course fees.

Refunds: Refunds will be made only if a written request for withdrawal is received on or before **May 1, 2002**.

Scholarship Program: A limited number of scholarships are available for full time college students wishing to attend a short course. Please check the scholarship box on the registration form. For additional information on scholarships, contact Heidi Ruffner at (505) 286-1308. Application deadline is **May 1, 2002**.

**For additional information, please contact AVS/NMC
Short Course Committee Chairperson, Dr. Heidi Ruffner,
at (505) 286-1308, FAX (505) 286-1308, jaruffn@sandia.gov**

Course Descriptions

A - Basic Vacuum Technology

Instructors: David Adams, Bill Boedeker, Chuck Peeples, Bill Powell, Chuck Walker, and Woody Weed

5 days, Mon.-Fri, May 13 – 17, 2002

Fee: \$1,295

Course Description: This course presents an introduction and overview of all principle elements of vacuum technology. First and foremost, it teaches the common terminology of, and provides reference to, the body of vacuum technology. It presents the vacuum fundamentals essential to an understanding of why vacuum pumps, systems, and processes are designed, operated, and maintained the way they are. The working principles of the pumps and gauges used on these systems are discussed, followed by a description of the pumps and gauges in current use. The characteristics required of components such as valves, connecting lines, flanges, and seals that are needed to connect the pumps to the process chamber are described, especially with regard to the application (i.e., medium, high, or ultra-high vacuum conditions). Materials normally used for vacuum systems are described, especially with regard to handling, fabrication, cleaning, and use in this demanding environment. System operation, preventative maintenance, and leak detection are also discussed with emphasis on practical applications. The lecture material is supplemented by two unique hands-on workshops covering vacuum systems and their operation and on leak detection. There is also a discussion of techniques used to troubleshoot systems that are operating at less than optimum levels.

Course Objectives:

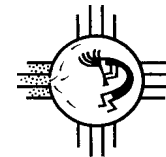
- An explanation of the vacuum fundamentals essential to operating, maintaining, designing, or using vacuum systems.
- Working principles and limitations of the pumps, gauges, and other components making up a vacuum system.
- Typical practices for operating vacuum systems, including analyzing and troubleshooting malfunctioning vacuum systems and leak detection.

- A discussion of the design concepts that are involved in matching the equipment and instrumentation to intended applications.
- Hands-on experience in operating vacuum systems and leak detectors and in actual leak detection.

Who Should Attend? The content of this course is designed especially for technologists first encountering the subject, but it will also be of value for those experienced in the subject. For those relatively new to the field, it provides the background required for effective participation in our specialized follow-on vacuum technology courses.

Students should bring a scientific calculator to this class.

Course Materials: Course Notes; *High-Vacuum Technology* by Mars Hablanian; *Vacuum Hazards Manual*, L.C. Beavis, V.J. Harwood and M.T. Thomas, AVS Monograph.



B - Operation and Maintenance of Vacuum Pumping Systems

Instructor: Jack Singleton

2 days, Mon. & Tues., May 13 & 14, 2002

Fee: \$875

Course Description: The major thrust of this course is to show how vacuum pumping systems can be operated most effectively, to achieve maximum performance while holding downtime for maintenance to a minimum. Typical procedures used for systems that employ oil-sealed rotary, Roots, vapor diffusion, turbo-molecular, sputter-ion, and cryogenic pumps are described. There are also discussions of possible variations in typical procedures that may be used in special cases.

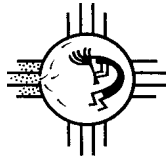
Troubleshooting and performance-testing techniques are presented as well as methods of leak detection that are most effective for operating vacuum systems.

Course Objectives

- Learn to operate vacuum pumping systems efficiently with minimum downtime.
- Learn about preventive maintenance on pumps and pumping systems.
- Understand leak detection in operating vacuum systems.
- Learn to troubleshoot and test the performance of vacuum pumping systems.

Who Should Attend? Those who want to learn how to properly operate vacuum systems themselves or are responsible for people who operate them. Knowledge of operating limits and general characteristics of pumps, gauges, and other auxiliary equipment used in vacuum systems is needed.

Course Materials: Course Notes.



C - Vacuum System Design

Instructor: Howard Patton

1 day, Mon. May 13, 2002

Fee: \$625

Course Description: This course deals with the principal aspects of system design, including materials selection, fabrication techniques, pump selection, sizing pumps and vacuum piping to a chamber, determining pump down time, leak rate specification, and surface preparation procedures. Methods for determining ultimate pressures are also discussed.

The course demonstrates that establishing the vacuum environment is the primary criterion for designing, constructing, and operating a vacuum system. A wide range of vacuum environments is discussed, from rough to ultrahigh vacuum, with emphasis on achieving a well-defined degree of vacuum.

The course compares calculated results from both hand calculations and commercially available computer software (not included with course material).

Course Objectives

- Learn how to select materials and fabricate vessels and components.
- Learn how to maintain a proper in-chamber environment.
- Understand the calculations and steps for vacuum pumping system design.
- Learn about the design and fabrication of vacuum systems.

Who Should Attend? Those familiar with the fundamentals of vacuum technology who are responsible for vacuum system design or fabrication and control of the in-chamber environment.

Course Materials: *Vacuum Technology* by Roth.

D - An Introduction to Ellipsometry

Instructor: Harland Tompkins

1 day, Tues. May 14, 2002

Fee: \$625

Course Description: This course is an introduction to ellipsometry and is directed toward the casual user. Single-wavelength is covered in a manner that introduces the student to spectroscopic ellipsometry. For comparison and contrast, we also discuss reflectometry briefly. One of the strengths of spectroscopic ellipsometry is the ability to measure the thickness of several layers simultaneously and we discuss the methodology required to do this. Another strength is the ability to obtain the spectrum of optical constants and to subsequently determine microstructural information, and we discuss how this is done. The course emphasizes physical phenomena, while including a minimum of mathematics.

Understanding the basics will allow the user to understand normal operations as well as stretch the technique beyond turnkey applications. The class will discuss applications of the techniques in the areas of microelectronics, corrosion, organic film deposition, monolayers and others.

The assumption is that the equipment is available and is working properly. No time will be spent on equipment design, setup, repair, or alignment.

Course Objectives:

- Understand the physical phenomena involved in ellipsometry.
- Learn how the optical properties of the material affect the ellipsometric parameters measured.
- Learn how to determine optical properties and film thickness.
- Learn how to use different parts of the spectral range to maximize the information output.
- Learn how to draw microstructural conclusions from the resulting optical constants.

Who Should Attend? Scientists, engineers, technicians, and others who use ellipsometry in the analysis of thin films.

Course Materials: *Spectroscopic Ellipsometry and Reflectometry: A User's Guide* by Harland G. Tompkins and William A. McGahan.

E - Vacuum Leak Detection

Instructor: Woody Weed

1 day, Wed. May 15, 2002

Fee: \$525

Course Description: This course is an introduction to the technology and practice of leak detection. It includes a discussion of the types of leaks that are to be expected in vacuum systems and how they affect the leakage rate. The principles of leak detection and the methods of putting these principles into practice are described. Practical techniques for detecting and locating leaks are provided with special attention to making the most effective use of the mass spectrometer leak detector.

Also covered in detail are the various ways in which mass spectrometer leak detectors can be connected to vacuum systems and their effects on obtaining satisfactory results from the test procedures. A method of verifying the effectiveness of the leak detection system before starting a test is described. The use of a residual gas analyzer (RGA), a partial pressure gauge, in detecting leaks and analyzing vacuum system difficulties is also discussed.

Course Objectives:

- Learn how to analyze vacuum systems and other closed systems for leaks during operation.
- Learn to use mass spectrometer leak detectors and residual gas analyzers to locate and measure leaks.
- Know the most effective ways to connect a mass spectrometer leak detector or residual gas analyzer to a vacuum system.

Who Should Attend? Those involved in leak detection of vacuum and other closed systems and those who need to evaluate whether a given leak rate is acceptable or unacceptable. A working knowledge of vacuum equipment and instrumentation and familiarity with the basic equations for throughput, pumping speed, and conductance is helpful.

Course Materials: Course Notes.

F - Cryopump Technology

Instructor: Kimo Welch

1 day, Wed. May 15, 2002

Fee: \$625

Course Description: This course reviews basic vacuum concepts, discusses the operation of diffusion pumps and turbo pumps, and looks at the modern cryopump in detail. Mechanical refrigerators, cryopump design, pumping speed, throughput, crossover pressures, regeneration, and effects of high-temperature heat sources and how to deal with them as well as ultimate vacuum are covered.

A substantial portion of this course is devoted to the practical application of these pumps to a variety of systems. The specific systems to be discussed are determined by class interest and discussion.

Attendees will gain a more complete understanding of basic vacuum technology and concepts and will thereby better understand the benefits and limitations of turbo pumps, diffusion pumps, and cryopumps. Attendees will also learn how to operate their vacuum systems to reach the required pressures in faster and cleaner ways.

Course Objectives:

- Understand vacuum and vacuum pump technology.
- Know the benefits and limitations of equipment types selected for system integration.
- Understand cryopumps and their operating benefits and limitations plus the basics of turbo pumps and diffusion pumps.
- Learn about the problems and solutions of current vacuum equipment and specific vacuum issues.

Who Should Attend? Maintenance technicians, process engineers, and equipment engineers interested in the application and use of cryogenic vacuum pumps. A basic understanding of vacuum pumps and vacuum systems is recommended.

Course Materials: Course Notes and *Capture Pumping Technology, An Introduction* by Kimo Welch.

G - Plasma Etching and Reactive Ion Etching

Instructor: John Coburn

G1 Fundamentals 1 day, Thurs., May 16, 2002

Fee: \$525

G2 Fundamentals and Applications

2 days, Thurs. & Fri., May 16 & 17, 2002

Fee: \$775

Course Description: This course discusses plasma-assisted etching phenomena and equipment in a manner that will assist the user in understanding and developing plasma etching and reactive ion etching (RIE) processes. The emphasis is on the fundamental physical and chemical processes that determine the consequences of a reactive-gas plasma/surface interaction; the role of energetic ions as encountered in RIE environments is discussed in particular detail. The silicon-fluorine system is used frequently to illustrate specific phenomena; etching of other materials, such as aluminum, organic solids, and GaAs, is also covered.

Other topics for discussion include the electrical aspects of RF glow discharges, plasma diagnostics, etching uniformity, etching selectivity, etching of high-aspect-ratio features, surface contamination and damage, and etching approaches using ion beams and high-density glow discharges.

Course Objectives:

- Understand the surface science aspects of RIE, including the role of energetic ion bombardment.
- Know the electrical aspects of RF glow discharges and the influence of electrode area.
- Understand the characteristics of various diagnostic and process monitoring methods.
- Learn the qualitative aspects of plasma chemistry that are important in dry etching.

Who Should Attend? Scientists, technicians, and others working with or interested in the dry etching of materials with reactive gas glow discharges.

Course Materials: Course Notes.

H - Microfabrication Technology for Micro-electromechanical Systems

Instructor: Stella Pang

1 day, Thurs. May 16, 2002

Fee: \$525

Course Description: In micro-electromechanical systems (MEMS), both electrical and mechanical devices are formed. Often, the mechanical devices consist of movable components that are partially separated from the substrate they are anchored to. In some cases, special films with unique properties for sensing or mechanical movement are needed. Although the basic principles of the IC technologies used in Si can be applied, there are many unique requirements for MEMS fabrication. In this short course, various microfabrication technology for MEMS will be introduced. Process design and factors for precise dimension control for MEMS will be covered. Issues related to integrating mechanical and electrical components will be discussed. Current technology trends for MEMS with examples in mechanical, optical, and chemical sensing and actuation will be given. New development of MEMS technology in the future will be addressed.

The specific topics covered are:

- Patterning by optical, x-ray, and focused ion beam lithography.
- Selective wet etching processes.
- Directional dry etching processes.
- Thin-film deposition by evaporation, sputtering, electroplating, chemical vapor deposition, and laser assisted deposition.
- Bonding and release of mechanical structures.
- MEMS technology for mechanical, optical, and chemical sensors.
- Future trends and development in MEMS technology.

Course Objectives:

- Learn various microfabrication technology for MEMS.
- Understand unique requirements for MEMS fabrication.
- Learn process design and control.
- Learn about merging mechanical devices with circuits.
- Learn current trends and future technology direction for MEMS.

Who Should Attend? Engineers, scientists, technologists, and technical managers with an interest in the development and implementation of microfabrication technology for microelectromechanical systems.

Course Materials: Course Notes.

I - Partial Pressure Analyzers: Analysis and Applications

Instructor: Len Beavis

1 day, Fri. May 17, 2002

Fee: \$525

Course Description: To fully understand vacuum system phenomena (i.e., residual gas levels, chemical modification, desorption and adsorption, contaminants, etc.), knowledge of PPAs is essential. These instruments are the major source of information about what is happening in a vacuum system.

The key design criteria and parameter trade-offs of all the major types of PPAs (quadrupole, time-of-flight, magnetic, etc.) are discussed. The effect that ion source design, resolution, ion energy, sensitivity, detector type, etc., have on the final spectrum are discussed in detail.

The interpretation of mass spectra due to inorganic species, solvents, hydrocarbons, and so on is discussed by working through actual mass spectra, peak by peak. The determination of individual gas contributions to spectra resulting from a mix of multiple gases is examined by working out examples. Applications are presented on the use of PPAs with regard to plasmas, various process atmospheres, desorption, leak detection, and contamination.

Attendees are encouraged to ask questions and to bring their own PPA problems to class.

Course Objectives:

- Understand ion formation, ion mass separation, and ion detection schemes.
- Know the interaction of partial pressure analyzer (PPA) parameters with each other and with the vacuum system.
- Learn about the formation and interpretation of mass spectra.
- Learn about actual applications of PPAs, residual gas analyzers (RGAs), and mass spectrometers.

Who Should Attend? Engineers, technicians, and scientists working with PPAs, RGAs, and mass spectrometers in vacuum systems dealing with materials modification, materials analysis, fusion, surface analysis, thin-film fabrication, plasma diagnostics, and applied problem solving.

Course Materials: Course Notes and *Partial Pressure Analyzers and Analysis* from the AVS monograph series.

J - Focused Ion Beams: Principles and Applications

Instructor: Mike Visale

1 day, Fri. May 17, 2002

Fee: \$525

Course Description: This one-day course begins with a discussion of the evolution and principles of operation of the liquid metal ion source (LMIS). The ion optics and features of the ion column are then presented, and then the way these components are incorporated into a FIB system is shown, along with a discussion of current FIB instrumentation.

The interaction of ions with matter is presented to the extent needed to understand the sputtering process. Sputtering yield as a function of sputtering ion parameters is investigated. Explanation is made of the ion beam assisted chemical vapor deposition (CVD) process and the gas source method that is used to improve etch rate.

The ability to sputter and deposit at less than 10 nm resolution makes possible a wide range of FIB applications. Applications discussed include:

- Imaging – grain size measurements.
- Ion implantation – few nm lateral resolution.
- Mask repair – modification and defect removal.
- Micro-machining – hard disk write heads, micro-mechanical systems (MEMS).
- Integrated circuit (IC) modification – cut-and-paste operations.
- Scanning electron microscopy (SEM) sample preparation – failure analysis techniques.
- Transmission electron microscopy (TEM) sample preparation – site-specific capability.
- Secondary ion mass spectrometry (SIMS) – description of SIMS process, lateral resolution, sensitivity.

Course Objectives:

- Become familiar with the principles of the generation and control of focused ion beams (FIBs).
- Know the capabilities of current instrumentation.
- Learn the varied applications of FIB techniques in manufacturing and research.

Who Should Attend? Scientists, engineers, and others who would like to be able to determine the concentration of elements as a function of depth from a solid surface.

Course Materials: Course Notes.

Meet the Instructors

David P. Adams is a Principal Member of the Technical Staff at Sandia National Laboratories. Currently in the Thin Film, Vacuum and Electronic Packaging Department, his interests include thin film deposition and analysis techniques, nucleation and growth, surface science, microstructure and stress evolution, mechanical properties of coatings and micromachining with focused ion beams. David received a bachelor's degree in Physics from the University of Virginia in 1989 and a PhD in Materials Science and Engineering from the University of Michigan in 1994. He is a member of the American Vacuum Society, the Materials Research Society and the American Society of Precision Engineering. He has authored more than 30 peer-reviewed, technical journal articles.

Len Beavis is a Consultant on materials and processes associated with vacuum and vacuum devices. He recently retired from Sandia National Laboratories where he was a Distinguished Member of the Technical Staff. His experience includes over 40 years in vacuum science and technology, including over 35 years in partial pressure analysis. He has published more than 100 papers and articles and authored several patents. He has taught many courses in vacuum technology, mass spectrometry (PPA), modern physics, and materials and processes for Sandia and the AVS. He is an Honorary Member and a Past President of the AVS.

Bill Boedeker is a Senior Technician, Los Alamos National Laboratory, in the Meson Physics Group. His areas of interest are vacuum hardware, joining, and leak detection.

John Coburn is a Research Associate in the Department of Chemical Engineering of the University of California at Berkeley. From 1968 to 1993, he was a Research Staff Member and Manager at IBM Research Laboratory in San Jose, California. During 1993-94, he was an Alexander von Humboldt Senior Scientist at the Fraunhofer Institute for Applied Solid State Physics in Freiburg, Germany. His scientific interests are associated with the fundamental aspects of plasma processing, plasma etching in particular. He has been an AVS member since 1969 and has been active in the Society at the national, divisional, and chapter levels. He has been teaching the AVS course on Plasma Etching and RIE since 1980.

Stella Pang is a Professor in the Electrical Engineering and Computer Science Department at the University of Michigan. From 1981 to 1989, she was with Lincoln Laboratory, Massachusetts Institute of Technology, working on submicrometer technology for microelectronics applications. Her research interests include nanofabrication technology, dry etching, and dry deposition for microelectromechanical, microelectronic, and optical devices. She received a Ph.D. in Electrical Engineering and Computer Science from Princeton University in 1981. She has over 250 technical papers, book chapters, and presentations. She is Fellow of IEEE and ECS.

Howard Patton has been an engineer for more than 37 years at Lawrence Livermore National Laboratory. Now semi-retired, he divides his time among the Laboratory, teaching, and consulting. Prior to his retirement, he was a lead project engineer for the Beamlet and National Ignition Facility. In addition to designing large lasers and vacuum systems he has been involved in a variety of vacuum processes, including microelectronics fabrication, optical coating, fusion research, vacuum joining, vacuum isotope separation, vacuum deposition, and space simulation. He is also a consultant to the US Department of Energy National Laboratories in the fields of vacuum, contamination control, and laser engineering. He has taught vacuum courses in the US, Canada, Mexico, South America, Europe, Asia, and Australia and has been an AVS instructor for more than 25 years. He is an Honorary Member of the AVS.

Chuck Peebles is a retired Senior Technical Assistant in the Surface Metallurgy Group at Sandia National Laboratories. His interests are

Jack Singleton, a consultant living in Monroeville, Pennsylvania, has had 25 years of experience in the practical aspects of vacuum at the Westinghouse Research Laboratories. He has worked with all types of pumps, total and partial pressure measurements, leak detection, and troubleshooting, including extensive work in achieving and maintaining ultrahigh vacuum conditions. He has been involved in the design and construction of systems for all pressure regimes, from incandescent lamp studies to a molecular beam epitaxy system.

Harland Tompkins is with the Motorola's Phoenix Corporate Research Lab in Tempe, Arizona, and has been with Motorola since 1985. He received his doctorate in physics from the University of Wisconsin-Milwaukee and worked for 12 years at the Bell Laboratories. His specialties are thin-film studies in microelectronics, applied surface science, and vacuum technology. He has authored more than 75 technical papers, 3 AVS monographs, and a book. He has been an AVS member since 1972; has been active in the Society at the national, divisional, and chapter levels; and has been a short course instructor for the AVS since 1978.

Chuck Walker has been a member of the technical staff in the Thin Film, Vacuum, and Packaging Department at Sandia National Laboratories since 1985. His work interests are brazing process development and vacuum hardware design. He earned a B.S. in Chemical Engineering from the University of New Mexico.

Michael Vasile is a consultant on focused ion beam technology and on the application of focused ion beams to the formation of microstructures. His research includes ion milling in three dimensions, micromachining of tips for scanning probe microscopy, and ion induced deposition of metal and insulator films at the micron and sub-micron scale. He did basic research in physical chemistry, and applied research in VLSI processing between 1968 and 1993 at Bell Laboratories, Murray Hill NJ. He retired as a Distinguished Member of Staff and continued an academic career as the Tolbert Pipes Professor at the Institute for Micromanufacturing, Louisiana Tech University between 1993 and 2001. He has over 100 publications and four patents. Additional teaching experience includes courses given at Rutgers University, Stevens Institute of Technology, and Carleton University. Invited Lectures include the Japan-US Seminar on Ion Nanobeams, Osaka, 1997, the Electrochemical Society, New Orleans, 1993, the Tenth Accelerator Conf., Univ. North Texas, 1988, the Electrochemical Society, Atlanta, 1988, and the International Dry Process Symposium, Tokyo, 1982.

He received his Ph.D. from Princeton University, and did Post-Doctorate research at the National Research Council of Canada.

Woody Weed is a Principal Member of the Technical Staff at Sandia National Laboratories in Albuquerque, New Mexico. He is part of the Thin Film, Vacuum, and Multi-Chip Modules Department, where he is currently designing vacuum pumping systems for laser inertial confinement fusion systems. Other recent work includes process development and deposition of metal hydride thin films, optical coatings, electronic neutron tubes, and thin films for flat panel displays. He worked on similar programs from 1983-1990 at the Lawrence Livermore National Laboratory. He is also active in the areas of vacuum system design, leak detection, partial pressure analysis, and material outgassing studies. He is Past Chair of the Vacuum Technology Division of the AVS and teaches various courses in applied vacuum technology for the DOE National Labs and the AVS. He was previously an instructor at Las Positas College in Livermore, California.

Kimo Welch has been an active member of the AVS since 1958 and a short course instructor since 1965, teaching various courses including Total and Partial Pressure Gauging, Basic Vacuum Technology, and forms of Capture Pumping and Cryopumping. He earned his B.S. degree from the University of the Pacific and an M.S. degree in electrical engineering from Stanford University. Over the last 40 years he has worked as a technician, engineer, R&D manager, manufacturing operations manager, P&L manager and General Manager in vacuum-related disciplines at General Electric, Raytheon, SLAC, Varian, Litton, Brookhaven National Laboratory, and Ebara, and is presently an independent consultant. He has authored three books; the most recent *Capture Pumping Technology, An Introduction* (1991), more than 40 articles, and holds 14 patents.